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MATTIE BOOKER
FAST AURORA ZONE ANALYSIS
FLIGHT DYNAMICS DIVISION
CODE 554.2
AUGUST 7, 1991

I. INTRODUCTION

THE FLIGHT DYNAMICS FACILITY (FDF) OF THE FLIGHT DYNAMICS DIVISION (FDD), CODE 550 OF THE GODDARD SPACE FLIGHT CENTER PROVIDES ACQUISITION DATA TO TRACKING STATIONS AND ORBIT AND ATTITUDE PRODUCTS AND SERVICES TO SCIENTISTS AND MISSION SUPPORT ELEMENTS. IT ALSO PERFORMS ORBIT AND ATTITUDE DETERMINATION AND ANALYSIS. I WAS ASSIGNED TO SPEND MY SUMMER AS A MEMBER OF THE NORTH CAROLINA A & T GRADUATE INTERN PROGRAM AND WORK ON A PROJECT THAT WOULD BE OF MUTUAL BENEFIT TO ME AS A STUDENT AND TO NASA PERSONNEL. MY PROJECT WAS TO DETERMINE A METHOD TO USE TO FIND THE SPACECRAFT ENTRY AND EXIT TIMES OF THE AURORA ZONE. TO GET FAMILIAR WITH THE INFORMATION, I READ VARIOUS BOOKS ON THE AURORA, AND ORBIT DETERMINATIONS. ONE OF THE BOOKS CALLED "SPACECRAFT ATTITUDE DETERMINATION AND CONTROL" BY JAMES R. WERTZ, HELPED ME TO GET FAMILIAR WITH THE TERMINOLOGY AND MATHEMATICAL EQUATIONS USED FOR MY PROJECT.

II. BACKGROUND INFORMATION

THE FAST AURORAL SNAPSHOT TELESCOPE (FAST) IS THE SECOND MISSION OF THE SMALL CLASS EXPLORER (SMEX) PROGRAM. IT IS DESIGNED TO BE A 1-YR. MISSION WITH LAUNCH CURRENTLY PLANNED FOR SEPTEMBER, 1994. FURTHERMORE, THE ASSUMED ORBITAL ELEMENTS FOR CURRENT STUDIES ARE LISTED BELOW:

EPOCH: MIDPOINT OF NORTHERN CAMPAIGN	**JAN. 15, 1994 0HR. 0 MIN. 0 SEC. GREENWICH MEAN TIME (GMT)**
SEMIMAJOR AXIS:	**8653.166 KM**
ECCENTRICITY:	**0.222462 DEG**
INCLINATION:	**83.00000 DEG**
RA OF ASCENDING NODE:	**84.21000 DEG**
ARGUMENT OF PERIGEE:	**288.5400 DEG**
MEAN ANOMALY:	**0.000000 DEG**

(THESE ELEMENTS REFLECT A 350km x 4200km ORBIT WHERE APOGEE AND PERIGEE PRECESS THROUGH TWO REVOLUTIONS PER YEAR). FAST WAS DEVELOPED FOR THE INVESTIGATION OF THE PLASMA PHYSICS OF AURORAL PHENOMENA AT EXTREMELY HIGH TIME AND SPATIAL RESOLUTIONS, UTILIZING FAST DATA SAMPLING AND TO INVESTIGATE THE PLASMA PHYSICS AT LOW ALTITUDE AURORAL ZONE. THE PROJECT SCIENTISTS HAVE A WAY OF DETERMINING WHEN THE FAST SPACECRAFT ENTERS AND EXITS THE AURORA ZONE. THESE SCIENTISTS WILL BE LOCATED AT POKER FLATS (ALASKA) FOR THE NORTHERN CAMPAIGN. THE NORTHERN CAMPAIGN IS DEFINED TO BE THE 60 DAYS PERIOD CENTERED AROUND JANUARY 15, 1995. DURING THE NORTHERN CAMPAIGN, APOGEE WILL BE OVER THE NORTH POLE. THE MISSION OPERATION MANAGER (MOM) AND FLIGHT OPERATION TEAM (FOT) STATIONED AT GODDARD WOULD LIKE TO HAVE THEIR OWN

ESTIMATE OF THE SPACECRAFT ENTRY AND EXIT TIMES THROUGH THE AURORA ZONE. THE FLIGHT DYNAMICS FACILITY HAS BEEN REQUESTED TO PROVIDE THE MOM AND FOT WITH THIS INFORMATION.

TO MEET FAST'S NEEDS THE PROJECT IS CONSIDERING THE FOLLOWING TRACKING STATIONS LOCATIONS TO SUPPORT FAST: POKER FLATS (ALASKA), SANTIAGO (CHILE), CANBERRA (AUSTRALIA), WALLOPS ISLAND (VIRGINIA), AND GOLDSTONE (CALIFORNIA). THE TRANSPORTABLE TRACKING EQUIPMENT IS AN ANTENNA DISH AND OTHER EQUIPMENT THAT CAN BE TRANSPORTED FROM ONE PLACE TO ANOTHER WILL BE POSITIONED AT POKER FLATS. TRACKING DATA CONSISTS OF MEASUREMENTS SUCH AS DOPPLER, ANGLES OR RANGE WHICH WE USED IN THE ORBIT DETERMINATION (OD) SYSTEM TO PROVIDE POSITION AND VELOCITY OF THE SPACECRAFT AT A GIVEN TIME OR AN EPHEMERIS FOR A SPECIFIED PERIOD OF TIME. THESE GROUND STATIONS SEND COMMANDS UP TO FAST. THEY PROCESS THE RETURN SIGNAL TO PROVIDE TRACKING AND TELEMETRY DATA.

III. STATEMENT OF PROBLEM (MY SUMMER PROJECT)

DETERMINE WHEN THE FAST SPACECRAFT ENTERS AND EXITS THE AURORA ZONE. THE MOM AND FOT WANT TO KNOW THE ENTRY AND EXIT TIMES OF THE SPACECRAFT IN THE AURORA. ONE APPROACH CONSIDERED WAS TO SELECT A GEOGRAPHICAL REGION, FORM A GEOMETRICAL SHAPE WHERE THE AURORA MAY OCCUR, AND THEN OVERLAY THE RESULTS ON A MAP TO SEE THE LATITUDE AND LONGITUDE OF THE ENTRY AND EXIT TIMES OF THE AURORA ZONE. THE APPROACH THAT I TOOK, WITH THE HELP OF CHARLIE PETRUZZO (CODE 745), WAS TO CONSIDER THE RELATIVE POSITIONS OF THE SUN AND THE MAGNETIC NORTH POLE. THESE TWO ELEMENTS HAVE GREAT EFFECTS ON THE AURORA. THE MAGNETIC NORTH POLE LOCATION IS 289.3 DEGREES LONGITUDE AND 78.6 DEGREES LATITUDE.

IV. METHODOLOGY

COMPUTATIONS WERE MADE TO DETERMINE THE FAST SPACECRAFT ENTRY AND EXIT TIMES AT THE AURORA ZONE AND THEIR CORRESPONDING SUBSATELLITE PROJECTIONS ON THE EARTH. FIRST, THE AURORA CONE'S VERTEX IS POSITIONED AT THE CENTER OF EARTH. THE AURORA CONE HAS A HALF ANGLE THAT IS EQUAL TO 23 DEGREES. THE REASON FOR USING A 23 DEGREES HALF ANGLE IS BECAUSE THE HIGH ALTITUDE USED FOR THE SPACECRAFT IS AT APOGEE (4200KM). MOREOVER, THE AURORA CONE IS ALTITUDE DEPENDENT. TO FIND THE POSITION OF THE CONE'S AXIS, CONSIDER THE SUN POSITION AND THE GEOGRAPHICAL NORTH POLE (GNP) POSITION. THE GEOGRAPHICAL NORTH POLE RIGHT ASCENSION IS 0 DEGREE AND THE DECLINATION IS 90 DEGREES. THIS IS CONVERTED TO A UNIT VECTOR. A CROSS PRODUCT IS USED WITH THE SUN POSITION AND THE GEOGRAPHICAL NORTH POLE. THE FOLLOWING EQUATION IS :

$$\vec{UY} \times \vec{UZ} = \vec{UX} \qquad \text{(EQ. 1-1)}$$

WHERE UY IS THE UNIT VECTOR FOR THE SUN'S RIGHT ASCENSION ON THE EQUATORIAL PLANE, UZ IS THE UNIT VECTOR FOR THE GEOGRAPHICAL NORTH POLE POSITION, AND UX IS THE NEW UNIT VECTOR WHICH COMPLETED THE DEFINITION OF THE RIGHT HAND COORDINATE SYSTEM. THE MAGNETIC NORTH POLE (MNP) IS ROTATED 4 DEGREES AWAY FROM THE SUN ABOUT THE NEW UNIT VECTOR. THE RESULTING UNIT VECTOR OF ROTATING

THE MAGNETIC NORTH POLE AWAY FROM THE SUN, IS THE AURORA AXIS. THESE COMPUTATIONS WERE USED TO CONSTRUCT FIGURE 1 WHICH SHOWS THE RIGHT HAND COORDINATE SYSTEM AND THE 4 DEGREES ROTATION. THE REASON FOR THE 4 DEGREES ROTATION IS BECAUSE THE SCIENTISTS STATE THAT THE AURORA CONE IS AFFECTED BY THE SOLAR WINDS, WHICH ARE PARTICLES CONSISTING MAINLY OF PROTONS AND ELECTRONS THAT FLOW OUT FROM THE SUN WITH A SUPERSONIC SPEED, PUSHING THE MAGNETIC FIELD. THE MAGNETIC NORTH POLE POSITION DOESN'T CHANGE IN THIS CASE, BUT IT IS USED TO DETERMINE WHERE THE AURORA AXIS IS LOCATED. THE ROTATION IS AS FOLLOWS:

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(PHI) & \cos(PHI) \\ 0 & -\sin(PHI) & \cos(PHI) \end{bmatrix} \begin{bmatrix} UM \\ \\ \end{bmatrix} = \begin{bmatrix} UA \\ \\ \end{bmatrix} \qquad \text{(EQ. 1-2)}$$

WHERE PHI IS THE ROTATION ANGLE, UM IS THE UNIT VECTOR OF THE MAGNETIC NORTH POLE, AND UA IS THE RESULTANT UNIT VECTOR FOR THE AURORA AXIS.

NOTE: IF THERE IS NO ROTATION OF 4 DEGREES, THEN THE AURORA AXIS IS AT THE RIGHT ASCENSION AND DECLINATION OF THE MAGNETIC NORTH POLE.

NEXT, COMPUTE THE SEPARATION ANGLE BETWEEN THE AURORA AXIS AND THE SPACECRAFT POSITION. HENCE, CHECK THE POSITION OF THE SPACECRAFT AT A GIVEN TIME. TO DETERMINE IF THE SPACECRAFT IS IN/OUT OF THE AURORA CONE, GET THE DOT PRODUCT OF THE AURORA AXIS AND THE SPACECRAFT POSITION. THE DOT PRODUCT IS USED BECAUSE WE WILL BE ABLE TO DETERMINE THE SEPARATION ANGLE. THE SEPARATION ANGLE IS OBTAINED BY TRANSFORMING THE DOT PRODUCT EQUATION:

$$UA \bullet S/C = \begin{cases} |UA|\,|S/C|\,\cos(THETA), & \text{IF } UA \neq 0 \text{ AND } S/C \neq 0 \\ 0, & \text{IF } UA=0 \text{ OR } S/C=0 \end{cases}$$

TO

$$(THETA) = \cos^{-1}((UA \bullet S/C) / (|UA|\,|S/C|)) \qquad \text{(EQ. 1-3)}$$

WHERE UA IS THE AURORA AXIS, S/C IS THE SPACECRAFT POSITION, AND THETA IS THE ANGLE BETWEEN UA AND S/C. FURTHERMORE, IF THE SEPARATION ANGLE BETWEEN THE AURORA AXIS AND THE SPACECRAFT POSITION IS GREATER THAN 23 DEGREES, THEN THE SPACECRAFT IS OUT OF THE CONE. HOWEVER, IF THE SEPARATION ANGLE IS LESS THAN OR EQUAL TO 23 DEGREES, THEN THE SPACECRAFT IS IN THE CONE. PERFORM THIS PROCESS AT 1 MINUTE INTERVALS (CHECKING POSITIONS OF SPACECRAFT AND SUN):

$$t(n) + 1' = T \qquad \text{(EQ. 1-4)}$$

WHERE t(n) IS EQUAL TO THE EPOCH, AND T IS THE RESULTANT TIME. THIS PROCESS CONTINUES UNTIL WE FIND A GOOD APPROXIMATION. THE TIME AND THE POSITION OF THE SPACECRAFT IS TAKEN FROM THE EPHEMERIS FILE WHERE AS THE SUN POSITION IS TAKEN FROM THE SOLAR LUNAR PLANETARY FILE (SLP). THESE POSITIONS MUST BE TAKEN AT CORRE-

SPONDING TIMES. ONCE THESE FILES ARE COMPLETED, THE PROCESS MAY END. IT MAY TAKE THE SPACECRAFT APPROXIMATELY 18 TO 26 MINUTES TO GO COMPLETELY THROUGH THE AURORA CONE. THE SAME PROCEDURE IS USED IF WE ARE EXITING THE AURORA CONE. FIGURE 2 OF THE CELESTIAL SPHERE SHOWS THE PROCEDURE THAT WAS USED FOR THE SPACECRAFT ENTRY AND EXIT TIMES OF THE CONE (VIEWER SEES THE RIM OF THE CONE FROM THE TOP POSITION). FINALLY, THERE IS AN EXAMPLE THAT GIVES A DESCRIPTION OF HOW THE PROCESS IS USED WITH REAL DATA.

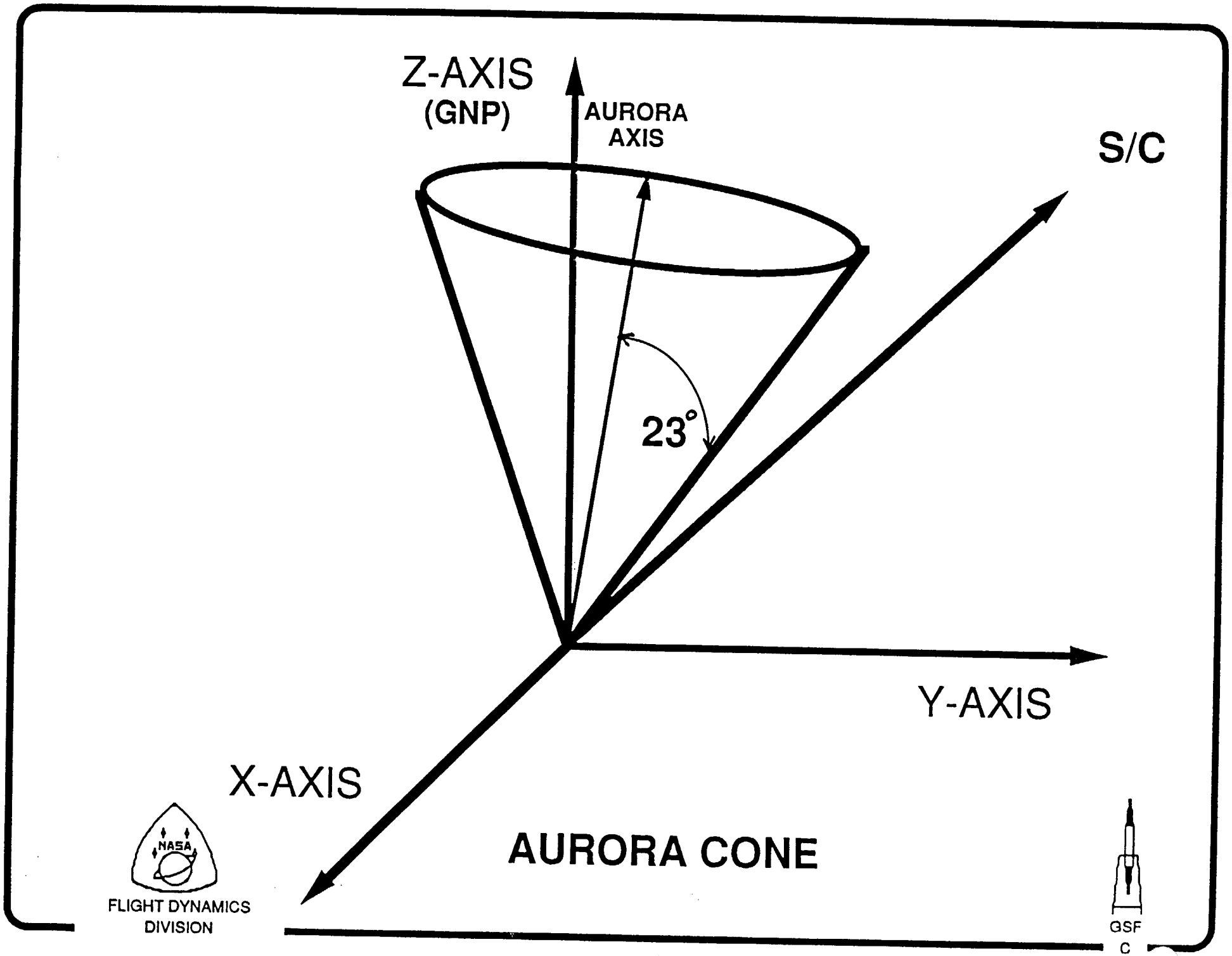

Z-AXIS
(GNP)
AURORA
AXIS
S/C
23°
Y-AXIS
X-AXIS
AURORA CONE
NASA
FLIGHT DYNAMICS
DIVISION
GSF
C

FIGURE 1

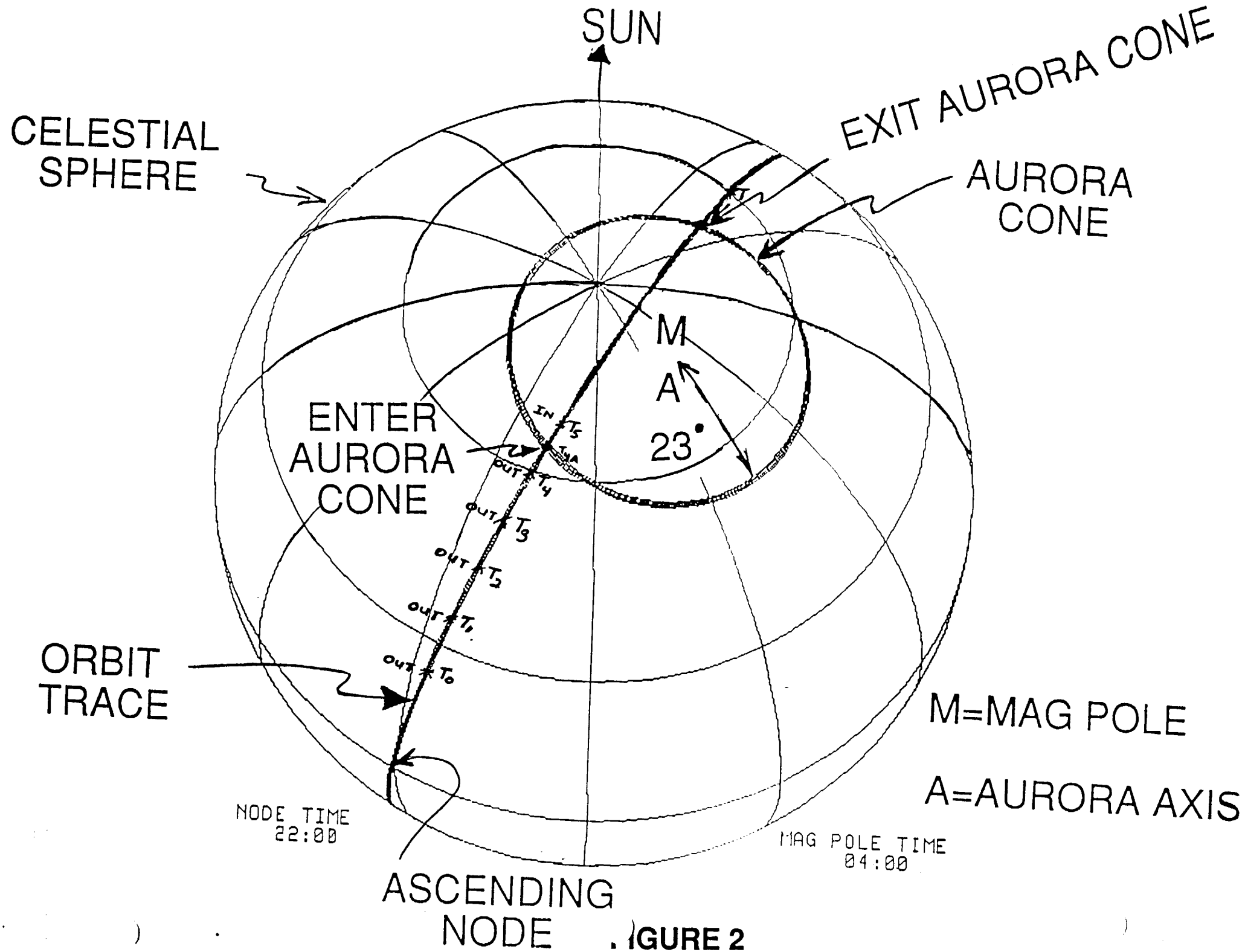

SUN
CELESTIAL SPHERE
EXIT AURORA CONE
AURORA CONE
M
A
23°
ENTER AURORA CONE
IN T_5
T_{5A}
OUT T_4
OUT T_3
OUT T_2
OUT T_1
OUT T_0
ORBIT TRACE
M=MAG POLE
A=AURORA AXIS
NODE TIME 22:00
MAG POLE TIME 04:00
ASCENDING NODE

FIGURE 2

V. EXAMPLE:

GIVEN: UA CONE = 23 DEGREES HALF-ANGLE
UA POS. = ROTATE MNP 4 DEGREES AWAY FROM THE SUN

EPOCH: JAN. 15, 1994 0HR. 0 MIN. 0 SEC. GREENWICH MEAN TIME (GMT)

	RIGHT ASCENSIONS	DECLINATIONS
MNP POS. =	289.3 DEG	78.6 DEG
SUN POS. =	296.5 DEG	-21.2 DEG
GNP POS. =	0.0 DEG	90.0 DEG
S/C POS. =	-49.97 DEG	-70.34 DEG

BY EQUATION 1-1, WE CAN APPLY THE CROSS PRODUCT OF THE TWO VECTORS:

$$0.4162961, -0.834205, -0.361662) \times (0.00000, 0.00000, 1) = \vec{UX}$$

WHERE $\vec{UX}$ = (-0.834205, -0.4162961, 0.000000) IS THE NEW UNIT VECTOR. THE MAGNETIC NORTH POLE UNIT VECTOR IS

$$\vec{UM} = (0.06532854, -0.1865492, 0.9802712).$$

THIS UNIT VECTOR UM IS ROTATED 4 DEGREES ABOUT THE NEW UNIT VECTOR UX. THE RESULTANT UNIT VECTOR IS

$$\vec{UA} = (-0.5372502, -0.6299052, -0.447607)$$

WHERE UA IS THE AURORA AXIS. FROM THIS RESULT, ONE CAN CONSTRUCT THE AURORA CONE WITH THE 23 DEGREES HALF ANGLE.

SINCE WE KNOW THE POSITIONS OF THE CONE AND THE SPACECRAFT, WE CAN FIND THE ANGLE BETWEEN THEM BY USING DOT PRODUCT FROM EQUATION 1-3. HERE IS THE FOLLOWING

$$\vec{UA} = (-0.5372502, -0.6299052, -0.4476070)$$

AND

$$\vec{S/C} = (0.21637380, -0.2575849, -0.9417178)$$

WHERE UA AND S/C ARE DEFINED ON PAGE 3. THE SEPARATION ANGLE BETWEEN THE TWO DATA IS 60.21419 DEGREES. SINCE THE ANGLE IS GREATER THAN 23 DEGREES, WE ARE OUT OF THE CONE. THIS PROCESS CONTINUES UNTIL THE SEPARATION ANGLE IS LESS THAN OR EQUAL TO 23 DEGREES.

VI. SUMMARY

FROM THE INFORMATION GIVEN, IT IS CLEAR THAT THIS METHOD IS FEASIBLE. THIS METHOD CAN GET A BETTER ESTIMATE WITH THE TIME OF THE SPACECRAFT ARRIVAL AND DEPARTURE OF THE CONE. THE AURORA CONE WAS DEFINED, AND THE IDENTIFIED ALGORITHMS FOR DETERMINING THE SPACECRAFT ENTRY AND EXIT TIMES OF THE AURORA CONE ARE KNOWN. FLIGHT DYNAMICS DIVISION (FDD) CAN NOW COMPLETE THE REQUIREMENTS AND SPECIFICATIONS FOR SOFTWARE. AS A RESULT, THESE ALGORITHMS CAN BE IMPLEMENTED IN SUPPORT OF THE FLIGHT DYNAMICS DIVISION TO DETERMINE THE SPACECRAFT ENTRY AND EXIT OF THE AURORA ZONE.

FAST AURORA ZONE

ANALYSIS

CODE 554.2 BLDG 23

BY MATTIE BOOKER

AUGUST 6, 1991

FLIGHT DYNAMICS
DIVISION

GSF

AGENDA

INTRODUCTION

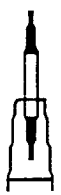
BACKGROUND INFORMATION

STATEMENT OF PROBLEM

METHODOLOGY

SUMMARY

FLIGHT DYNAMICS
DIVISION



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BACKGROUND

FAST AURORAL SNAPSHOT TELESCOPE

LAUNCH DATE: SEPT., 1994

NORTHERN CAMPAIGN: JAN. 15, 1995
(+-30 days)

INCLINATION: 83 DEGS.

PERIGEE: 350 KM

APOGEE: 4200 KM

PERIOD OF ORBIT: 2 HRS. 13 MINS.; 133MINS.

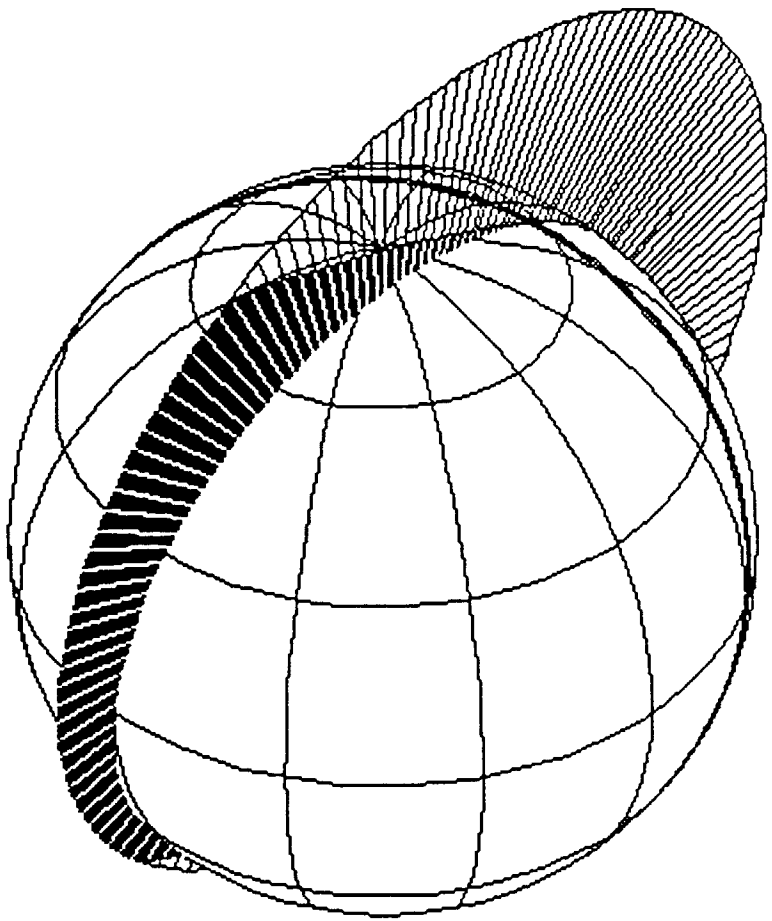
MISSION LIFE: 1 YEAR

FLIGHT DYNAMICS
DIVISION

GSF

ALT= 4200/350
INCL = 83
RAAN = 87
22.00 HR
ARGP = 290
STEP = 60

Y/M/D = 94/01/15
SUN RA= 297
DEC= -21
BETA= 25



DRAWN
5-AUG-91
12:24
GSFC 745

VIEW FROM
RA - 132
1.00 HR
DEC - 40

STATEMENT OF PROBLEM
(RESEARCH & DEVELOPMENT)

INVESTIGATE A CONCEPTUAL APPROACH
TO MEET THE PROJECT REQUIREMENT:

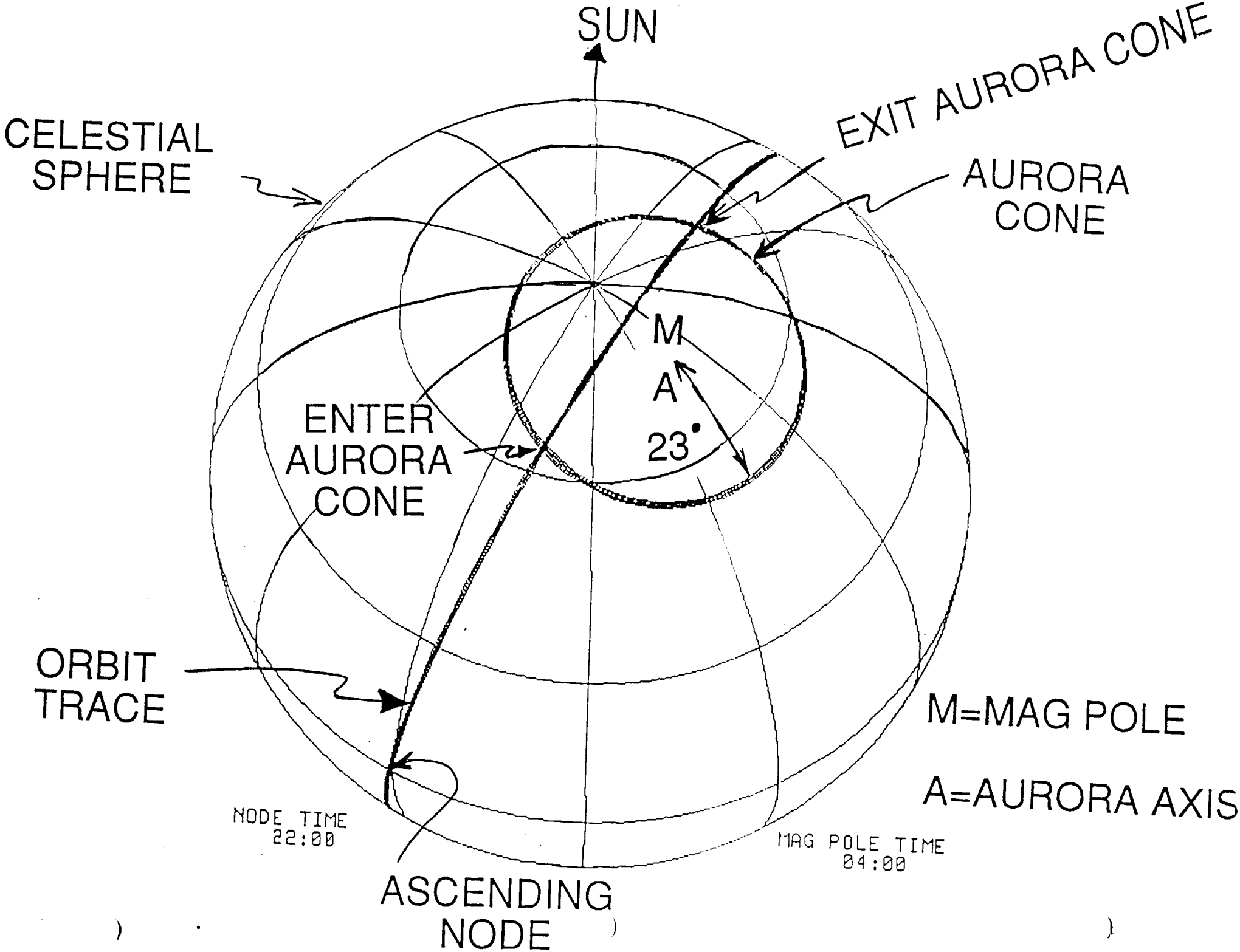
TO DETERMINE THE SPACECRAFT ENTRY
& EXIT TIMES OF THE AURORA ZONE

PURPOSE

TO PROVIDE FOT LOCATED AT GODDARD
WITH AN ESTIMATE OF ENTRY & EXIT TIMES

FLIGHT DYNAMICS
DIVISION

GSF


SUN
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EXIT AURORA CONE
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M
A
23°
ENTER AURORA CONE
ORBIT TRACE
M=MAG POLE
A=AURORA AXIS
NODE TIME 22:00
MAG POLE TIME 04:00
ASCENDING NODE

METHODOLOGY

TO FIND AURORA CONE AXIS:

$$\vec{RA\ OF\ SUN} \times \vec{GEO.\ N.\ POLE} = \vec{ROTATION\ AXIS}$$

$$[ROTATION\ MATRIX]\ \ \vec{[MAG.\ N.\ POLE]} = \vec{[AURORA\ AXIS]}$$

FLIGHT DYNAMICS
DIVISION

GSF
C

METHODOLOGY (CON'T)

TO FIND SEPARATION ANGLE, $\ominus$,

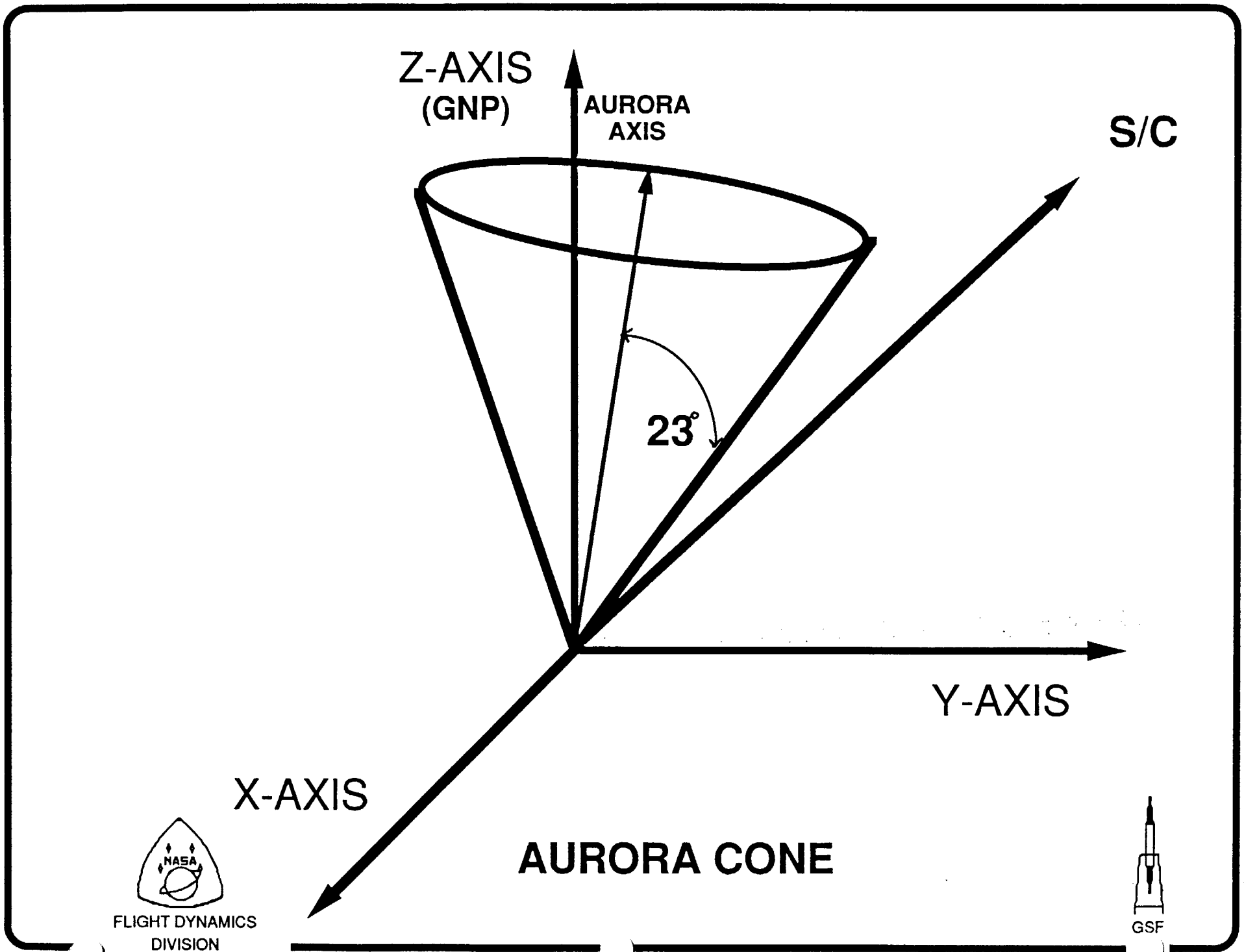
BETWEEN CONE AND SPACECRAFT:

$$I \bullet J = \cos \ominus$$

WHERE I & J ARE UNIT VECTORS FOR AURORA AXIS AND S/C REFERENCED TO CENTER OF THE EARTH

SEPARATION ANGLE $<=$ 23 DEG. ; IN

SEPARATION ANGLE $>$ 23 DEG. ; OUT


Z-AXIS
(GNP)
AURORA
AXIS
S/C
23°
Y-AXIS
X-AXIS
AURORA CONE
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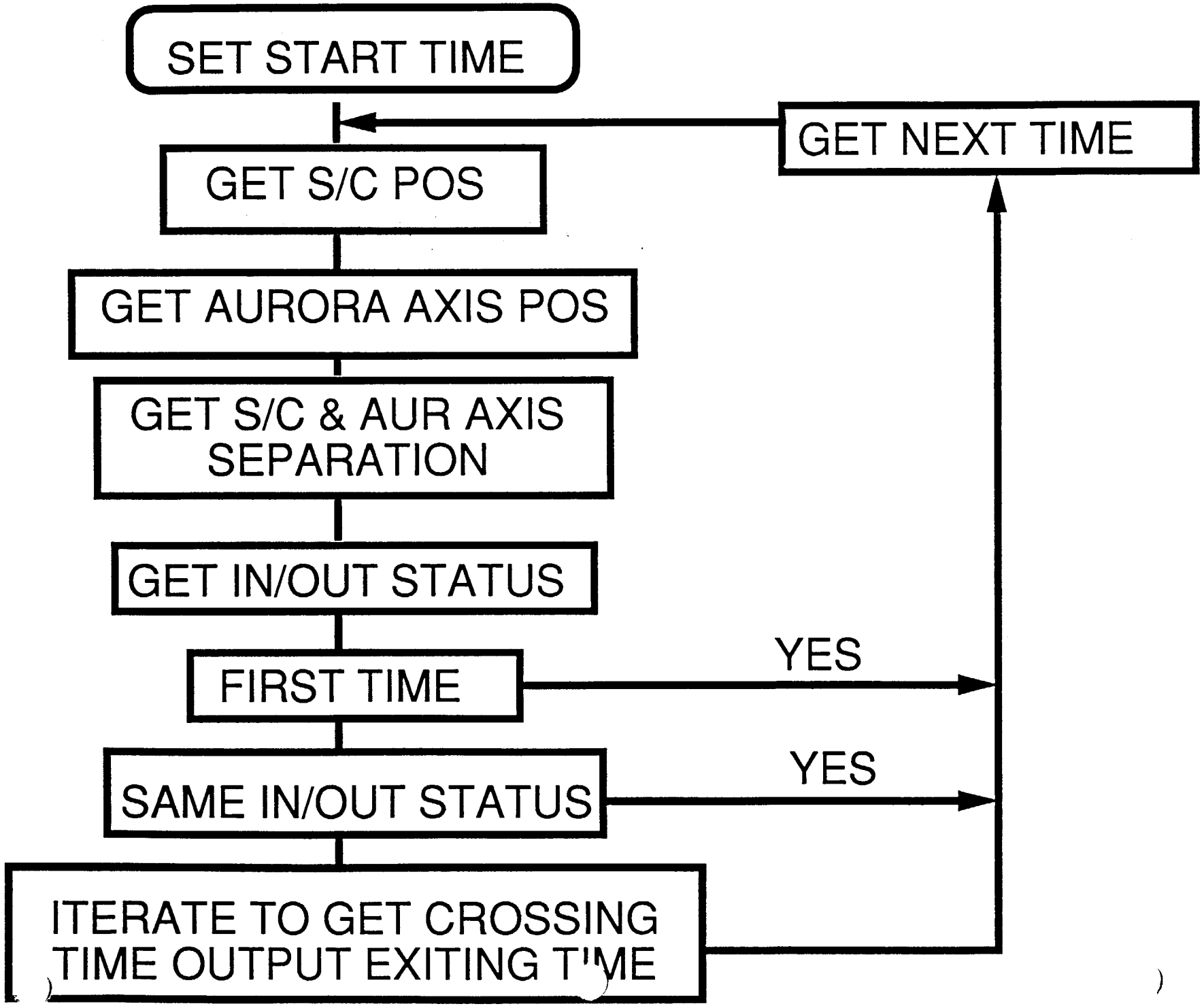
FLIGHT DYNAMICS
DIVISION
GSF


SET START TIME
GET NEXT TIME
GET S/C POS
GET AURORA AXIS POS
GET S/C & AUR AXIS SEPARATION
GET IN/OUT STATUS
FIRST TIME
YES
SAME IN/OUT STATUS
YES
ITERATE TO GET CROSSING TIME OUTPUT EXITING T'ME

SUMMARY

CONE WAS DEFINED

IDENTIFIED METHODS FOR DETERMINING ENTRY & EXIT TIMES

FDD CAN NOW COMPLETE REQUIREMENTS & SPECIFICATIONS FOR SOFTWARE

ALGORITHM MAY BE IMPLEMENTED IN SUPPORT OF THE FDD FAST REQUIREMENT